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Ultrafast, Chipscale Light Deflector Enabling an All-Optical, Solid-State Streak Camera

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The rapid deflection of beams has been used to record the time history of events at many timescales. Conventional, electron-based streak cameras represent the fastest embodiment of this concept but are limited by space-charge effects that blur the focused beam when high signal amplitudes are present. This forces a tradeoff between temporal resolution and dynamic range. A streak camera that deflects a beam of photons would eliminate this tradeoff.

Unlike electron beams that are readily manipulated via electromagnetic forces, the sustained deflection of an optical beam through many picosecond-scale resolvable spots has been historically difficult to achieve. For each resolvable spot of deflection in the far-field, the near-field wavefront must be rapidly tilted by 1 wave. Nonlinear optical mechanisms based on the Kerr effect are ultrafast [1] but also ultraweak, making them impractical. Optically excited carriers have a much stronger influence on the refractive index of a semiconductor. Due to a long-lived (nanosecond scale) electron-hole recombination time, they have been often overlooked as a means for devising ultrafast optical switches. We demonstrate a deflector concept that achieves picosecond response exploiting these strong refractive index changes and actually benefits from long recombination times.

The device concept is illustrated in the figure. A signal beam carrying a temporal waveform is coupled into a planar waveguide. When the temporal region of interest is fully contained, a normally incident pump beam patterned by a serrated mask imprints a one dimensional array of prisms in the waveguide core. The prisms are generated via optical nonlinearities (plasma loading, band filling, and bandgap shrinkage) [2] that turn on rapidly and remain latched for the sweep. The signal then experiences a distributed deflection that is finely discretized over a large number of prisms. Because the prism array is created while the signal is in transit through it, later portions of the signal propagate through more prisms. The signal thus deflects in linear proportion to its time delay. The swept beam is focused onto a conventional camera for recording. We term this concept Serrated Light Illumination for Deflection-Encoded Recording (SLIDER) [3].

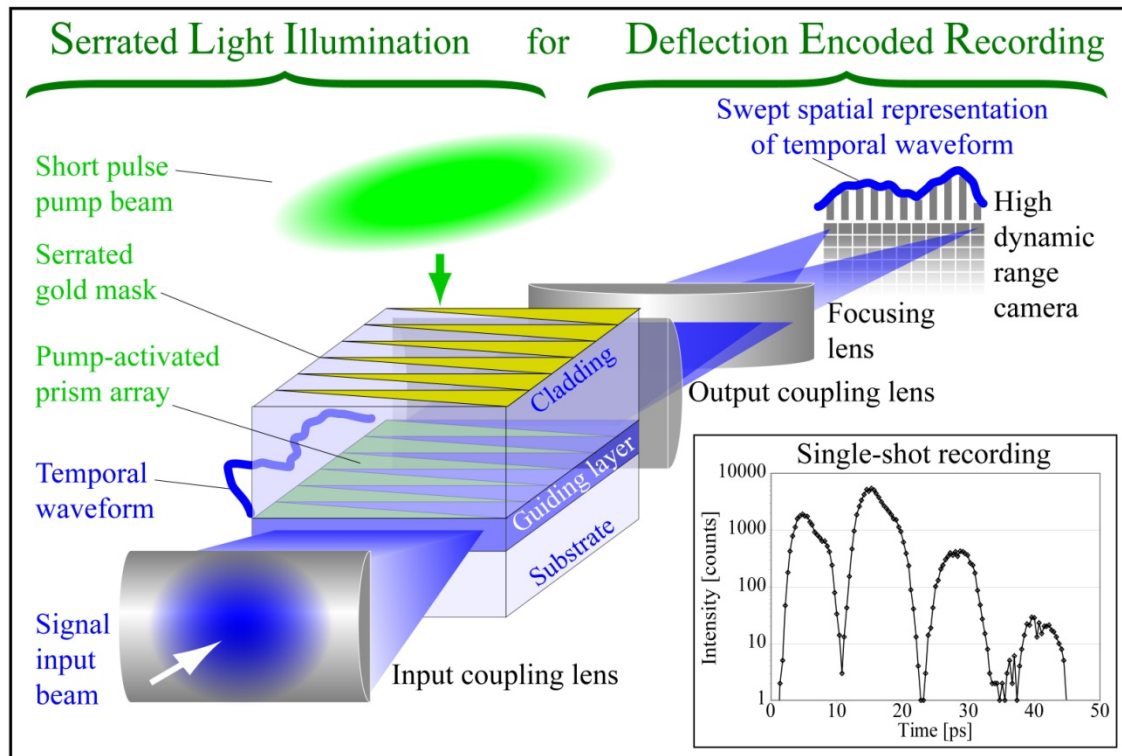
To test this concept, we fabricated a planar waveguide with a GaAs guiding layer, surrounded by AlGaAs claddings. A Ti:sapphire regenerative amplifier provided an above-bandgap (800 nm) 150 fs pump pulse that was spatially formatted to a uniform fluence of $65 \mu\text{J}/\text{cm}^2$. An optical parametric amplifier was used to generate a below-bandgap (950 nm) signal that was spectrally filtered to 1.4 nm (1 ps transform limited). A ring-down test pattern was then generated by a Gires–Tournois cavity with a round-trip time of 10 ps. The SLIDER device enabled a single-shot recording of 1 ps impulses resolved at 2.5 ps across a record of 50 ps. The dynamic range of the measurement was 3000:1, limited by the camera.

The SLIDER technique is potentially scalable to high dynamic range (10^4) across hundreds of picoseconds, making it a credible replacement technology for conventional streak cameras. The fabricated device yielded, to our knowledge, the fastest sustained optical deflection reported to date.

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References

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 2. B. R. Bennett et al. IEEE J. Quantum Electron. 26, 113 (1990).
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The SLIDER concept is based on the optically-induced deflection of an optical signal injected into a planar slab waveguide. The deflection is caused by a sequential array of prisms that are initially nonexistent, then simultaneously created by a sub-ps pump pulse while the signal is in transit. To achieve this effect, the pump beam passes first through a serrated transmission mask to acquire the prism pattern and then imprints the pattern into the refractive index profile of the guiding layer through rapid charge carrier excitation. Because the prism array is created while the signal is in transit through the pumped region, later

portions of the signal propagate through more prisms, leading to a linear mapping of time to deflection angle. The swept beam is then focused onto a camera that records a spatial representation of the temporal signal. The inset displays a single-shot recorded trace of a ring down test signal consisting of 1 ps impulses separated by 10 ps. A temporal resolution of 2.5 ps was maintained over a record of 50 ps. The dynamic range of the measurement was limited by the camera at 3000:1.

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